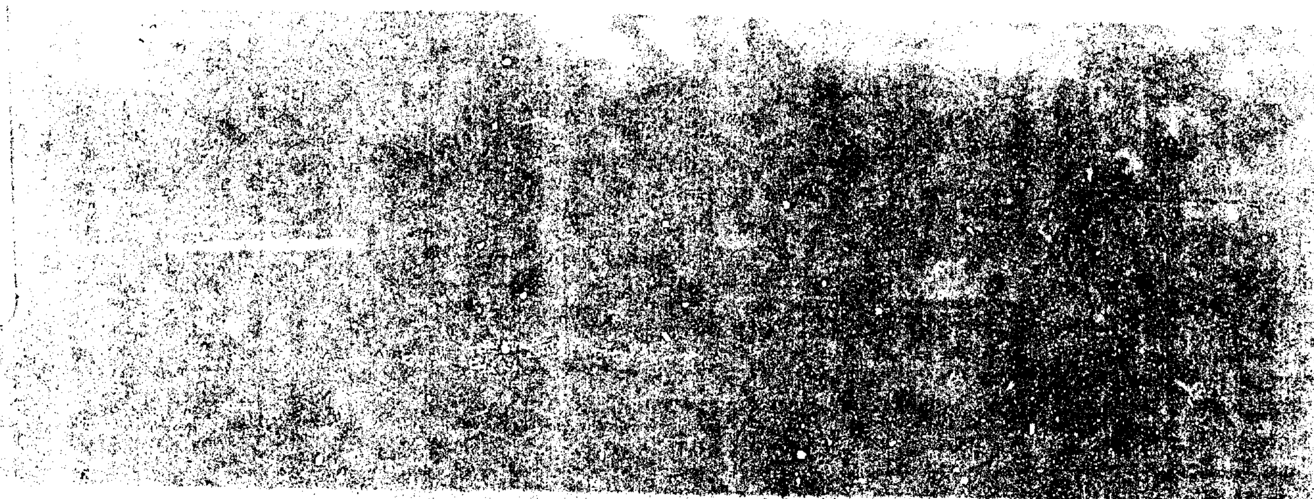
COMPARISON OF THE RIDE AND SHOCK RESPONSES OF THE M60 STB AND M60 HSS/ATB HYBRID TANKS



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A summary of the previous ride and shock tests with the various M60 Improved Suspension Configurations is presented. This summary is followed by a description of the final series of ride and shock tests in the M60 Improved Suspension Program. These tests were conducted at Fort Knox, Kentucky, to obtain data on the ride and shock characteristics of an M60 tank equipped with a mix of hydropneumatic (HSS) and advanced torsion bar (ATB) suspensions. This hybrid configuration, which is referred to as the M60 HSS/ATB hybrid tank, was recommended by the Scientific Advisory Group as the most feasible CONT

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and cost-effective suspension configuration. Experimental tests were conducted with the M60 HSS/ATB and an M60 with standard torsion bar suspensions (M60 STB), which served as a reference for comparison. No significant difference was noted in the ride performance of the two tanks; however, the M60 HSS/ATB could negotiate discrete obstacles at faster speeds than the M60 STB. These relational patterns agreed with those developed from the previous ride and shock tests, i.e., there were no significant differences in ride performance, but the tanks with the improved suspensions could negotiate discrete obstacles at faster speeds. This advantage was attributed to the extended wheel travel of the improved suspensions. The terms ride performance and ride quality were defined to depict two very different measures of the tank ride environment. Although there were no significant differences in ride performance, there were differences in ride quality. The improved suspensions generally provided the best ride quality, which agreed with the subjective responses of the tank crews. It is recommended that, in addition to the maximum limits determined by the driver response, ride conditions also be evaluated at the more common operational levels at the crew locations.

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PREFACE

The study reported herein was conducted during the spring of 1977 at Fort Knox, Kentucky, by the U. S. Army Engineer Waterways Experiment Station (WES) for the M60 Project Manager's Office (M60 PMO) and was authorized by Intra-Army Orders for Reimbursable Services (DA Form 2544) dated 17 March 1977.

The overall study was under the general supervision of Messrs. W. G. Shockley, Chief, Mobility and Environmental Systems Laboratory (MESL), E. S. Rush, Chief, Mobility Systems Division (MSD) and C. J. Nuttall, Jr., Chief, Mobility Research and Methodology Branch (MRMB), MSD. The MSD is now one of the divisions of the Geotechnical Laboratory. The field program was conducted by Mr. G. G. Switzer, formerly of MRMB, now with the Armor and Engineer Board, Fort Knox, Kentucky. The data were analyzed and the report was prepared by Mr. N. R. Murphy, Jr., MRMB.

Acknowledgment is made to the U. S. Army Armor Center and School and to the Logistics and Test Support Branch. U. S. Army Armor and Engineer Board, Fort Knox, Kentucky, for their support in this program.

COL J. L. Cannon, CE, was Director of WES during the conduct of this study and the preparation of the report. Mr. F. R. Brown was Technical Director.

CONTENTS

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI)
UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) as follows:

Multiply	By	To Obtain
feet	0.3048	metres
inches	25.4	millimetres
miles per hour (U. S. statute)	1.609344	kilometres per hour

COMPARISON OF THE RIDE AND SHOCK RESPONSES OF THE M60 STB AND THE M60 HSS/ATB HYBRID TANKS

PART I: INTRODUCTION

Background

1. This report presents a comparison of the measured ride and shock responses of two M60A1 tanks. One tank was configured with a standard torsion bar suspension referred to as the M60 STB, and the other was configured with a proposed improved suspension consisting of a combination of hydropneumatic and advanced torsion bar suspension and referred to as the M60 HSS/ATB hybrid. This marked the conclusion of the experimental ride and shock tests in the M60 improved suspension program. The M60 improved suspension program has been a rather long and complicated activity involving a number of Army agencies and private industry contractors. It holds a very important status in the overall M60 product improvement program which is designed to produce the M60A3 tank. The M60A3 tank is to be the companion tank to the XM1 in the U. S. tank force of the 1980's. A lack of improvement in its operational effectiveness with regard to cross-country mobility, agility, fire-on-the-move capability, reliability and maintainability (RAM) and ride quality/crew performance will limit its value as a true complement to the XM1 in countering a superior U. S. S. R. tank force. The U. S. Army Engineer Waterways Experiment Station (WES) has been involved as one of the supporting agencies in this product improvement program since its beginning. The WES has been concerned primarily with the ride, shock, and mobility evaluations. Experimental ride and shock tests have been conducted with various candidate suspension configurations. These tests have produced some meaningful yet controversial results. A detailed background of the events is included in this report to provide a more comprehensive understanding of the data and relations presented in this study.

2. The first tests with an improved suspension on the M60 chassis were conducted in March and April 1973 at Fort Knox, Kentucky. The study was initiated as a part of the M60 product improvement program and conducted under the direction of personnel from the Human Engineering Laboratory (HEL), Aberdeen Proving Grounds, Maryland, with support provided by the U. S. Army Armor and Engineer Board (USAARENBD). HEL asked WES to provide instrumentation to measure and record ride and shock data and to assist in the conduct of the tests. The primary purpose of the study was to obtain comparative data on the speed-made-good and gun-sighting performances provided by an M60 tank fully equipped with a tube-over-bar (TOB) suspension developed by the Chrysler Corporation and an M60 tank equipped with the standard torsion bar suspension (STB). However, HEL felt it would be appropriate to obtain some objective, quantitative measures of the ride and shock experienced by these tanks during these speed-made-good and gun-sighting tests. The overall results indicated that the TOB suspension might provide some notable improvements in performance. However, time constraints, adverse weather, maintenance problems, limited availability of the vehicles for testing, among other problems reduced the effectiveness of the program to the extent that no conclusive results were achieved.

3. Subsequent operational and reliability tests resulted in a rather large number of TOB suspension malfunctions. These frequent malfunctions along with the higher cost of the TOB suspension prompted some concern over the feasibility for its use on the product-improved tank. As a result, Chrysler proposed a hybrid system with the TOB suspension on only the first, second, and sixth roadwheels and the STB suspension on the third, fourth, and fifth roadwheels. It was believed this hybrid system would be more cost-effective by reducing both costs and suspension malfunctions while still providing a significantly improved ride performance over the M60 STB. A meeting was held at the Rodman Laboratory, Rock Island Arsenal, in August 1974, to identify requirements and establish a schedule for a TOB cost-effectiveness study. Three major questions evolved from this meeting: (a) How much improvement in cross-country mobility and speed can be obtained with the

TOB (hybrid) suspension configuration? (b) Will this improvement result in a significant increase in the system combat effectiveness? and (c) Is it cost-effective? It was decided that the answers to the last two questions could be readily accomplished through computer simulations using a Combat Simulation Model (DYNTACS), and a hit probability model developed by the General Electric Corporation (HITPRO) along with other selected performance and engineering models. The major requirements that were lacking and were essential inputs for the computer simulations were relations depicting the ride and shock limiting speeds for the competing tanks. In November 1974, at the request of the M60 Project Manager's Office (PMO), the WES conducted a few experimental tests at Fort Knox to measure and compare the ride and shock performance of the M60 TOB and M60 STB tanks. The quantitative results describing the chassis motions indicated that there were no significant differences in the tank ride performance but showed a rather substantial increase in the speeds at which the M60 TOB could cross a discrete obstacle. The WES test crew who rode the vehicles throughout the tests maintained that generally the ride of the M60 TOB was smoother and more comfortable. However, as the rides approached levels that were barely tolerable i.e., those rides approaching or exceeding the 6-watt ride performance criterion, no distinction was perceived between the rides of the two tanks. As a result of the experience from the first program with the fully equipped TOB suspension and preliminary computer simulations (performed by the Chrysler Corporation) that showed significant ride improvement over the M60 STB with the M60 TOB, it had been tacitly assumed that the M60 TOB tank would provide significantly higher ride limiting speeds than the M60 STB. Consequently, the results of the experimental tests caused much concern.

4. The WES cited several factors that could have had a significant effect on these results. Specifically, the test program was intended only to obtain some quick experimental data on the STB and TOB tanks to substantiate the assumptions and develop the necessary ride and shock relations for the computer simulations. As with the

first program, it was conducted under rigid time constraints, in inclement weather, and in test areas that did not possess the most desirable characteristics for ride test courses. One tank was configured with a T97 track and the other with a heavier T142 track. Due to the wet, slippery conditions, the tanks seldom were able to attain speeds that would produce ride- limiting conditions, and the relations were based primarily on extrapolations. Because of these shortcomings, the results of these tests were also considered to be inconclusive, and the computer simulations and comparative measures of effectiveness were postponed until a more comprehensive, better controlled program could be conducted.

5. Interest in the tactical capabilities of the main battle tank continued to grow. The battle tank was fast becoming a highly controversial weapon. The disastrous tank losses by the Israelis during the opening days of the 1973 war in the Mid-East brought about heavy criticism. Critics in Congress claimed the significant developments in antitank weapons had rendered the tank obsolete on the modern day battlefield. After considerable planning, a comprehensive M60 improved suspension study (M60 IS) was developed and approved by the M60 PMO. The National Waterlift Company (NWL) designed and built a hydropneumatic suspension system specifically for M60 series tanks. A test program was begun at Fort Knox in April 1976 to test this hydropneumatic suspension system (HSS) along with the TOB and STB suspensions. A more desirable range of test courses was available, and there were no time constraints to cause a hastily conducted program. Dry weather prevailed and provided consistent surface conditions throughout the program. Speeds that far surpassed acceptable ride tolerance levels were obtained on all three tanks. Nonetheless, the results were similar to those of the previous program; that is, there were no noticeable differences in the quantitative measures of ride performance among the three tanks, but there were significant differences in their shock performances. The M60 HSS was far superior to the M60 TOB and the M60 STB in its ability to negotiate single obstacles. However, the fact that the measurements did not reflect differences in ride

performance led to heavy criticism of the measurements and techniques used to determine ride performance. It seemed intuitively logical that the improved suspension should provide better ride performance, and most of the occupants stated that the ride of the tanks with the improved suspensions felt less severe than that of the M60 STB.

6. Some felt that the ride-comfort criterion--absorbed power--used successfuly in past experiments to evaluate vehicle ride was not a suitable descriptor. Consequently, several other quantities describing the hull motion of the tanks, such as rms values of linear and angular acceleration and peak acceleration distributions, were examined independently by WES and U. S. Army Tank-Automotive Research and Development Command (TARADCOM) personnel. The relations developed from these various quantities produced no changes in the ride performance comparisons. It appeared at this point that very little if any increase in ride-limiting speed could be attained by adding an improved suspension to the M60 chassis. This led to the belief that the terrain conditions at Fort Knox were not suitable for suspension evaluation since the surface was composed predominately of low-frequency, long-wavelength undulations, which would not exercise the vibration isolation properties of the improved suspension.

7. In an attempt to resolve this controversy, another test program was conducted at Aberdeen Proving Grounds (APG) in November 1976. At the request of the Chrysler Corporation, the M60 TOB was replaced by a tank fully equipped with a Chrysler-developed advanced torsion bar (ATB) suspension. This ATB suspension provided more wheel travel, better material, and more reliability and was more cost-effective than the TOB suspension. This tank was referred to as the M60 ATB. Test courses were found that consisted of higher spatial frequencies which should suitably excite the suspensions and reveal the relative effects of their vibration absorbtion capabilities. The belief that these test courses would reflect the expected ride differences was reinforced by the fact that recent tests on these courses with M60 STB tanks, the German LEOPARD II (AV), and the two XM1 prototypes, using the same instrumentation equipment and analysis techniques had revealed

significant differences among their ride-limiting speeds. Furthermore, the ride-limiting speed-surface roughness relations developed for the M60 STB tanks during these recent tests agreed with those developed for the M60 STB tanks from the previous tests at Fort Knox. Also, a series of tests with an M113 APC and the MICV on these courses just a week prior to these M60 IS tests revealed considerable differences in their ride-limiting speeds. These results, therefore, indicated that absorbed power was an accurate discriminator of ride performance. Unfortunately, this was not the case for the M60 IS vehicles. The results at APG were similar to those of the first two programs at Fort Knox, i.e., there were no significant differences in ride performance, but there were considerable differences in the ability to negotiate single obstacles. It is important to note that this advantage in shock performance applies only to single obstacles. Encountering succeeding obstacles while still under the vibrational influence of the past obstacle sometimes worsened the ride in the M60 IS vehicles. Also, it is worthwhile to mention that the harsh pitch motions of the underdamped M60 ATB tank quite often produced a more severe cross-country ride at the tank commander and loader observation seats than even that of the M60 STB.

8. Close observation during the tests at APG revealed that, particularly on the rougher courses, the harsh ride response was due to recurring jolts or impulses caused when the front sprocket or front part of the tank's hull impacted the terrain and not necessarily due to the suspension "bottoming out." These jolts occurred for all the tanks at about the same locations along the test courses, and it was obvious that the ride performance was influenced more by the tank-terrain geometry than the suspensions. Consequently, when comparing results in terms of ride performance, that is, the speed at which the driver can just barely tolerate the response, little difference was noted. However, when comparing the absorbed power levels at selected speeds there is a difference. Although the absorbed power levels did not differ much at the driver's position, the test data vividly demonstrated that the absorbed power measured at the tank commander's and loader's observation

seats was consistently the lowest for the M60 HSS tank at these selected operational speeds. This type of comparison corroborated the subjective comments of the tank crews who maintained that the ride of the M60 HSS felt the best, that is, the test measurements agreed consistently with the subjective rankings of the occupants. Consequently, the terms "ride performance" and "ride quality" were chosen to distinguish between these two types of ride comparisons. Ride performance is based on speed as the dependent variable. It is concerned with the speed at which the absorbed power reaches a tolerance limit. Ride quality is based on absorbed power as the dependent variable. It is concerned with the absorbed power levels that occur at a selected speed. This distinction between ride performance and ride quality is illustrated graphically in Figure 1. These lower absorbed power levels in the M60 HSS tank should have a significant influence on reducing crew fatigue and enhancing the quality of task performance. However, an important increase in performance in terms of speed most likely cannot be achieved by simply adding an improved suspension to the M60 chassis.

9. About this time, mobility and gunnery (fire-on-the-move) tests were being conducted by the Armor Center at Fort Knox. Also, similar gunnery tests were being conducted at the APG. Preliminary results indicated that the M60 HSS and M60 ATB tanks permitted slightly more effective firing-on-the-move. Gunners in these tanks with improved suspension could fire at faster speeds and on rougher courses than when in the M60 STB. Initial evalutions of absorbed power measurements at the gunner's position indicated that firing-on-the-move was almost totally ineffective at absorbed power levels beyond about 2 or 3 watts, which is about one third to one half of the 6-watt tolerance limit.

10. A compilation of the results at this stage of the study precipitated questions concerning the cost effectiveness of the M60 HSS. This led to the inception of the M60 Improved Suspension Cost and Operational Effectiveness Analysis (M60 IS COEA) and the establishment of a Scientific Advisory Group (SAG) to direct its activities. This group suggested that equipping a tank fully with the HSS was not cost-

effective and that a better compromise would be another hybrid configuration composed of the HSS on the first, second, and sixth roadwheels and the ATB on the third, fourth, and fifth roadwheels. This configuration was referred to as the M60 HSS/ATB hybrid tank.

11. An M60 HSS/ATB hybrid tank was configured at Fort Knox to be included in the latter stages of the gunnery and mobility tests to obtain experimental data for input to the war-gaming models and the combat effectiveness study being prepared for the COEA.* The M60 PMO requested that this tank also be made available for ride and shock tests. Time, weather, and scheduling problems seriously constrained the availability of the tank for ride and shock tests, and the tests had to be crowded in between the gunnery and the mobility tests. However, a sufficient amount of data was obtained to develop ride and shock relations for the M60 HSS/ATB hybrid tank. The results of this effort are the basis for this report.

Purpose

12. The purpose of these tests was to obtain experimental data on the M60 HSS/ATB hybrid tank to develop ride and shock performance relations for comparison with those of the other candidate tanks previously tested and for use in mobility and combat effectiveness computer simulations.

Scope

13. Two tanks, an M60 STB and an M60 HSS/ATB hybrid, were appropriately instrumented and run at various speeds over four cross-country courses in the Carpenter Test Area at Fort Knox, Kentucky. The M60 HSS/

* By this time the DYNTACS simulation model had been replaced by the CARMONETTE force interaction model as the primary force-on-force wargaming model for TRADOC studies. CARMONETTE is much less sensitive to ride performance.

ATB hybrid tank was also run over a set of discrete rigid obstacles. Since sufficient data had been obtained with the M60 STB during past programs, no additional obstacle tests were conducted with this tank. The discrete obstacle data were used to compare the shock performance of the tanks; the cross-country data were used to compare the ride. Ride measurements were made only at the driver's seat. Linear and angular acceleration measurements were made at a location near the vehicle's center of gravity. The data for determining the ride performance relations consisted primarily of vertical and total absorbed power at the driver seat. Peak accelerations at the driver seat were used to determine the shock performance relations. The M60 STB tank was run solely as a reference vehicle to provide a valid comparison with the performance relations obtained for the candidate tanks in the previous test programs.

PART II: EQUIPMENT, TEST COURSES, AND TEST PROCEDURES

Instrumentation

14. The instrumentation for measuring the dynamic responses was exactly the same as that which had been used in the previous programs, except that no measurements were made at the tank commander's or loader's observation seat. This was because of restraints on the on-going mobility tests. The instrumentation consisted of three orthogonally positioned linear accelerometers and two angular accelerometers mounted near the center of gravity of the vehicle to measure the bounce, fore-and-aft, side-to-side, pitch, and roll accelerations; three orthogonally positioned linear accelerometers on the driver's seat to measure the vertical, fore-and-aft, and side-to-side accelerations; and one vertically oriented accelerometer mounted on the floor beneath the seat.

15. All signals were recorded on FM magnetic tape by a 14-channel heavy-duty recorder, its associated signal processor, and 30-volt battery power source, which were all mounted on the vehicle. The three accelerometers on the driver's seat were also connected to a portable ride meter, which converted the accelerations to absorbed power (a measure of ride comfort). In addition to being recorded on tape, absorbed power was displayed continuously on a meter for visual observation of the responses occurring during each test. Also, the elapsed time and time-averaged absorbed power were obtained from a digital meter at the end of each test. For the discrete obstacle tests, the vertical accelerometer beneath the driver's seat was connected to a peak counter to display the number of occurrences of peak accelerations falling within four selected g-levels.

Test Courses

16. Four courses for ride performance evaluation were selected in the Carpenter Test Area (CTA) because the ongoing mobility tests in which the M60 HSS/ATB hybrid tank was involved were being conducted in

that area. The courses were in the same general locations as those CTA courses in the previous Fort Knox tests. The mobility tests were on a tight schedule, and ride tests were conducted whenever the tank could be made available. The surface roughness of the test courses ranged from 1.1 to 5.8 rms, in.,* and covered the surface roughness range at which M60 tanks would encounter ride limits.

17. Courses 1 and 2 were each 300 ft long and courses 3 and 4 were each 400 ft long. Each course was marked with flagged stakes at 100-ft intervals that were readily visible to the driver and observers in the test vehicles. The courses were profiled with rod and level on 1-ft intervals, and this information was processed to determine a roughness index (rms) for each course. The surface roughness values for each course are given below.

Course No.	Surface Roughness rms, in.
1	1.1
2	2.8
3	1.9
4	5.8

Photographs of representative portions of the ride courses are shown in Figures 2 and 3.

18. In addition to the ride courses, rigid, semicircular, 10-, 12-, and 16-in. high obstacles were positioned on a level, hard surface. Stakes were placed on either side of an approach lane, 100 ft from the obstacles to be used as timing markers for determining impact speed.

Test Procedures

19. Several tests were conducted with each tank on each course at relatively constant speeds ranging from about 5 mph to the maximum attainable speed.

* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 4.

20. Each test began with the tank positioned a sufficient distance from the beginning of the test course to enable the driver to reach the desired test speed before entering the course. This speed was then maintained at a relatively constant level (using the vehicle's speedometer) throughout the length of the course. Tests were conducted at similar speeds in both directions over the course until the maximum speed was reached, or until the driver reached what he believed to be the highest speed he could tolerate.

21. In addition to the driver, a WES observer rode in the tank commander's seat during each test to monitor the ride meter, direct the testing, and narrate the pertinent activities. This narrative was recorded on the FM magnetic tape. At the end of each test, the average absorbed power, elapsed time over the test course, and average speed were determined from the ride meter's digital displays. This procedure provided on-the-spot indications of absorbed power versus speed relations for use by field personnel in planning the sequence of the tests to ensure that sufficient data were obtained to develop the necessary relations. After each series of tests, the driver's comments on the rides were also recorded on the magnetic tape. The measurements and procedures were designed to be essentially independent of driver judgment and to provide direct, objective measurements of vehicle ride dynamics characteristics.

22. Several tests were conducted with the M60 HSS/ATB hybrid tank over each of the three discrete obstacles (10-, 12-, and 16-in. heights) at relatively constant speeds from 5 mph to the maximum permissible speed, usually in 5-mph increments.

23. Each test began by positioning the tank a sufficient distance from a timing stake so that the driver could achieve the desired test speed before reaching the stakes. He then maintained that speed (using the vehicle's speedometer) until the vehicle had completely crossed the obstacle. The vehicle-obstacle impact speed was computed from the distance and elapsed time between the stakes and the obstacle. Also, the number and magnitude of peak accelerations (g) occurring beneath the driver's seat were determined from the peak counter.

PART III: ANALYSIS OF DATA

Method of Analysis

24. Ride performance is customarily based on the vertical absorbed power at the driver's seat. Absorbed power, which is a measure of the rate at which vibrational energy is absorbed by a human, is a ride-comfort criterion established through a comprehensive laboratory test program at TARADCOM several years ago. Six watts was established as the human tolerance limit when vibration was in only the vertical mode. However, it has become increasingly evident from past tests that motions other than the vertical may often contribute significantly to ride comfort, particularly at positions located above the center of gravity, such as the tank commander's or loader's observation seat, whose fore-and-aft motions are heavily influenced by the vehicle's pitch motions. Consequently, although no measurements were made at the tank commander's or loader's observation seat, absorbed power at the driver's seat was calculated from the fore-and-aft and side-to-side motions, as well as the vertical, to provide this additional insight. Being a scalar quantity, absorbed power can be added to give a single quantity that represents the effects of all three motions. This arithmetic sum is referred to as total absorbed power. The 6-watt tolerance limits have not been confirmed for these combined motions. However, a presentation of the total absorbed power (the sum of the vertical, fore-to-aft, and side-to-side absorbed powers) is included to supplement the analysis in this report. The basic data obtained from the tests to describe the ride performance and vibration responses of the vehicles are listed for the M60 HSS/ATB hybrid and the M60 STB in Tables 1 and 2, respectively.

25. The basic ride relations are the vertical absorbed power versus speed plots shown in Figures 4-7 and the total absorbed power versus speed plots shown in Figures 8-11. These plots show the manner in which the vertical and total absorbed powers change as a function of changes in speed for each tank on each of the four courses. The

relations are delineated by smooth curves through the data points. These curves were drawn on the basis of the data, engineering judgment, and patterns developed from past experience.

26. The curves illustrate the characteristic nature of a tank's ride performance. From previous experience it has been noted that generally there is a specific "operational" speed region, the range of which depends on the nature of the terrain, at which the ride level is acceptable and at which the crew can properly perform their functions. A slight increase in speed beyond that range produces an intolerable ride. The new tactical doctrine and emerging interests in fire-on-the-move capabilities may render it more meaningful to evaluate tank ride in the operational speed regions and at other crew locations instead of focusing solely on the maximum limits determined at the driver's location.

27. From the relations shown in Figures 4-11 it appears, on the basis of comparing the speeds at equal absorbed power levels, that the M60 HSS/ATB hybrid tank may have a slight advantage over the M60 STB tank, although the M60 STB has the faster speed on course 4. The advantage, however, is not considered significant because, even at the highest absorbed power level, the greatest differences in speed were less than 3 mph. Previous experience has indicated that speed differences on the order of 2 mph do not warrant drawing any important conclusions concerning the relative performance of vehicles, and only when speed differences are greater than 3 or 4 mph can conclusions be made with reasonable confidence. If, however, a statistical analysis of the data with differences of 2 to 3 mph indicates statistical significance,* consideration should be given to its practical significance.

28. A ride-limiting speed versus surface roughness plot was developed for the two tanks from the corresponding 6-watt speeds determined from the vertical absorbed power relations in Figures 4-7. The result

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* Spanski, P., and Beck, D. R., "Evaluation of Improved Suspensions for the M60 Series Tank," Final Report, May 1977, Science and Technology Division, Tank-Automotive Research and Development Command, Warren, Mich.

is shown in Figure 12. The solid line is exactly the same as that drawn through the data from all previous tank tests that have been conducted by the WES. The dashed lines represent the spread of the previous data. It is seen that the new data fall within the spread, and the previously established curve fits the data equally well. The relations involving only vertical absorbed power were used to determine the ride-limiting speed-surface roughness relations for the reasons mentioned in paragraph 24.

Obstacle Tests

29. No obstacle tests were conducted with the M60 STB since the peak acceleration versus speed relationships had been suitably established from previous tests. The basic data for the M60 HSS/ATB hybrid tank in the form of maximum peak acceleration, which occurred at a given speed over an obstacle of a given height, are listed in Table 3. A plot of these peak accelerations versus speed is given in Figure 13. A similar plot for the M60 STB developed from data from the previous program is given in Figure 14 for comparison purposes. It is seen that the M60 HSS/ATB hybrid tank registered a 2.5-g shock limit level on only the 16-in. obstacle, while the M60 STB reached shock limits on both the 12- and the 16-in. obstacle. A shock performance curve in the form of speed at 2.5-g versus obstacle height was developed for the M60 HSS/ATB hybrid tank. Judgment and experience were exercised in constructing a curve through the one valid coordinate. Consideration was given to the pattern of the peak-g versus speed relations for each obstacle and the relational trends of the other tanks. This curve is presented in Figure 15 along with the curves for the other tanks involved in this program. The curve falls, as expected, between the M60 HSS and the M60 ATB tanks.

Ride Quality

30. As pointed out previously, ride-limiting speed does not present the complete picture for evaluating a tank's ride. It is only

representative of the maximum speed that the ride conditions will permit. It focuses emphasis solely on maximum response conditions and ignores the lower level response conditions at which tanks most often operate. It is certainly an important and relevant evaluation of performance for certain types of combat operations that require rapid movements. Such examples are rapid movements toward engagements with the enemy, reinforcement operations, or hasty movements to defensive positions. However, the results of a comprehensive series of cross-country operational tests conducted by USAARENBD with the M60 improved suspension tanks showed that the average absorbed power levels were in the range from 1.5 to 2.0 watts. Also, results of the gunnery tests indicated that firing on the move was virtually ineffective when the absorbed power levels at the gunner's station exceed levels of about 2 watts. This self-imposed 2-watt absorbed power level appears to be a good criterion for describing representative operational responses for tanks. It was also pointed out previously that although differences in the speeds of the M60 study tanks at selected absorbed power levels were small, differences in the absorbed power levels at corresponding speeds were often quite significant. To illustrate this for the two tanks in this study, the histograms in Figures 16 and 17 were developed. The main interest is to compare the absorbed power levels of the two tanks at corresponding speeds. It was decided to make the comparisons at those speeds at which the M60 STB tank (which is the reference vehicle) reached vertical absorbed power levels of 2, 4, and 6 watts at the driver, the reasoning being that 6 watts represented the maximum ride condition, 2 watts the operational ride condition, and 4 watts an intermediate response level. The speeds at which these 2-, 4-, and 6-watt levels occurred naturally differed for each course, but this method of selecting corresponding speeds from reference absorbed power levels provided direct comparisons of the absorbed power levels of the two tanks in terms of the maximum, intermediate, and operational condition of the M60 STB tank. The absorbed power levels at the corresponding speeds were determined from the absorbed power-speed plots as illustrated by the example in Figure 18.

31. The maximum responses for both tanks on course 1 were less than the 2-watts operational limit; therefore, the results of tests on this course are not included in the histograms. The histograms in Figure 16 show the respective vertical absorbed power comparisons on each course for each of the three reference levels. It is seen that the absorbed power of the M60 HSS/ATB hybrid tank is considerably lower than that of the M60 STB on courses 2 and 3, but the trend is reversed on course 4. The trend depicted on courses 2 and 3 is representative of the results of similar comparisons of the previous test programs. That is, the tanks with the improved suspensions generally provided lower absorbed power levels than the M60 STB at corresponding speeds. The ride of both tanks on course 4, which had the most severe surface roughness, consisted of repetitive jolting impulses due to the front sprocket and front part of the hull impacting with the terrain. These impacts were more numerous for the M60 HSS/ATB hybrid tanks, which caused a reversal in the expected trend. The same trend is seen in the histograms in Figure 17, which show comparisons of the total absorbed power for the same corresponding speeds and reference vertical absorbed power levels compared in Figure 16. A tabulation of the ride quality and ride performance data is listed in Table 4.

PART IV: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

32. Based on the data in this report and that of the previous test programs, it is concluded that:

a. There is no significant difference in the ride performance of the M60 STB and the M60 HSS/ATB hybrid tanks.

b. The M60 HSS/ATB hybrid tank can negotiate discrete obstacles at faster speeds than the M60 STB tank.

c. The ride performance data collected from this program blend with the data obtained from the previous tank test programs. The single curve established to represent the ride performance-surface roughness relation for the tanks in the previous studies also delineated the relations in these new data.

d. The greatest differences in ride-limiting speeds among all the tanks tested are less than 3 mph, with an average between 1 and 2 mph. This is not considered to be statistically nor practically significant.

e. The ride quality of the M60 HSS/ATB hybrid tank was better than that of the M60 STB on three of the four test courses.

f. Results of the last two test programs indicate that the ride of the M60 series tanks on terrains with surface roughness values greater than about 3.0 rms, in., is more influenced by the tank-terrain geometry than by type of suspension. Tank ride on these terrain roughnesses consists primarily of repetitive, jolting impulses from impacts of the front sprocket and front part of the hull with the terrain.

Recommendations

33. It is recommended that more emphasis be placed on evaluating the dynamic response levels at the more common operational speeds than on the speeds at which humans can barely tolerate.

Table 1

Ride Tests - M60 HSS-ATB Hybrid

Test No.	Time	Speed, mph	Average Absorbed Power, watts — On Driver's Seat — Vertical	Fore-Aft	Side-to-Side	Total
		Course 1, Surface Roughness = 1.1 rms, in., Elevation				
1	17.3	11.82	0.5	0.1	0.4	1.0
2	13.3	15.38	0.8	0.5	[illegible]	2.2
3	12.5	16.36	0.7	0.6	0.8	2.1
		Course 2, Surface Roughness = 2.8 rms, in., Elevation				
4	29.9	6.84	0.2	0.2	0.3	0.7
5	18.9	10.82	0.8	1.4	1.0	3.2
6	16.7	12.25	3.0	1.6	2.5	7.1
7	14.8	13.82	7.2	3.0	3.9	14.1
8	14.9	13.73	6.2	2.5	3.0	11.7
9	[illegible]	14.20	7.9	3.1	3.4	14.4
10	21.9	9.34	1.1	0.8	0.8	2.7
		Course 3, Surface Roughness = 1.9 rms, in., Elevation				
11	39.7	-	0.2	0.2	-	-
12	24.2	[illegible]	0.5	0.3	0.8	1.6
13	[illegible]	15.15	1.3	0.8	1.7	3.8
14	16.6	16.43	5.5	1.5	2.9	9.9
15	17.8	15.32	1.1	0.8	1.5	3.4
		Course 4, Surface Roughness = 5.8 rms, in., Elevation				
16	49.3	5.53	1.2	0.8	0.5	2.5
17	32.5	8.39	3.3	2.1	1.7	7.1
18	34.8	7.84	[illegible]	2.4	1.7	7.1
19	37.5	[illegible]	1.7	[illegible]	1.0	4.3
20	29.8	9.15	4.3	3.4	3.1	10.8
21	54.7	4.99	0.7	0.6	0.6	1.9
22	26.9	10.14	7.4	5.2	4.4	17.0
23	62.7	4.35	0.2	0.6	0.7	1.5

Table 2

Ride Tests - M60 Standard Torsion Bar (STB)

Test No.	Time	Speed, mph	Average Absorbed Power, watts On Driver's Seat: Vertical	Fore-Aft	Side-to-Side	Total
		Course 1, Surface Roughness = 1.1 rms, in., Elevation				
91	16.1	11.30	0.3	0.2	0.3	0.8
92	13.3	15.38	1.3	0.4	1.4	3.1
93	12.6	16.23	1.0	0.5	1.0	2.5
94	-	-	-	-	-	-
95	-	-	-	-	-	-
		Course 2, Surface Roughness = 2.8 rms, in., Elevation				
96	23.6	8.67	1.4	1.6	1.5	4.5
97	33.1	6.18	0.1	0.2	0.2	0.5
98	20.7	9.88	1.3	0.9	0.9	3.1
99	18.7	10.94	7.1	1.6	5.6	14.3
100	18.6	11.00	6.0	1.2	7.5	14.7
		Course 3, Surface Roughness = 1.9 rms, in., Elevation				
101	24.5	11.13	0.7	1.0	0.8	2.5
102	37.5	7.27	0.2	0.2	0.2	0.6
103	18.3	14.90	7.2	1.7	2.3	11.2
104	18.3	14.90	5.1	1.6	2.6	9.3
105	20.8	13.11	2.5	1.0	1.1	4.6
106	18.4	14.82	7.3	2.3	3.9	13.5
		Course 4, Surface Roughness = 5.8 rms, in., Elevation				
107	54.5	5.00	0.2	0.5	0.3	1.0
108	39.9	6.84	1.2	1.1	0.9	3.2
109	26.8	10.18	5.2	3.1	3.1	11.4
110	26.7	10.21	4.3	3.9	2.8	11.0
111	33.8	8.07	2.0	1.5	0.9	4.4
112	42.3	6.45	0.4	0.8	0.6	1.8
113	34.5	7.90	2.5	1.9	1.5	5.9

Table 3

Obstacle Impact Tests - M60 HSS/ATB Hybrid

Test No.	Obstacle Height in.	Speed, mph	Peak Acceleration, g
64	10	13	0.7
65	10	11	0.7
66	10	16	-*
58	12	8	0.9
59	12	13	1.1
60	12	17	1.3
61	12	16	1.0
62	12	16	0.9
63	12	20	0.9
67	16	5	0.7
68	16	9	1.0
69	16	12	2.3
70	16	12	1.9
71	16	14	2.8

* Obstacle broke loose from support.

Table 4

Ride Quality and Ride Performance Data

Course	Surface Roughness rms, in	Vertical Absorbed Power: Operational STB	Operational HSS/ATB	Intermediate STB	Intermediate HSS/ATB	Maximum STB	Maximum HSS/ATB	Total Absorbed Power: Operational STB	Operational HSS/ATB	Intermediate STB	Intermediate HSS/ATB	Maximum STB	Maximum HSS/ATB
		Ride Quality (Absorbed Power in Watts)											
2	2.8	2	0.2	4	0.6	6	0.5	6.2	2.6	11.0	3.6	14.2	5.0
3	1.9	2	0.5	4	0.7	6	0.8	4.0	2.0	6.2	3.7	8.6	3.2
4	5.8	2	3.0	4	5.8	6	8.0	4.6	6.9	10.6	4.3	18.0	22.0

Course	Surface Roughness rms, in.	2-watt Speed STB	2-watt Speed HSS/ATB	4-watt Speed STB	4-watt Speed HSS/ATB	6-watt Speed STB	6-watt Speed HSS/ATB
		Ride Performance (Speed in mph)					
2	2.8	9.8	11.9	10.5	12.8	11.0	13.7
3	1.9	12.7	15.6	14.2	16.2	14.8	16.3
4	5.8	8.0	7.3	9.8	9.0	10.8	10.0

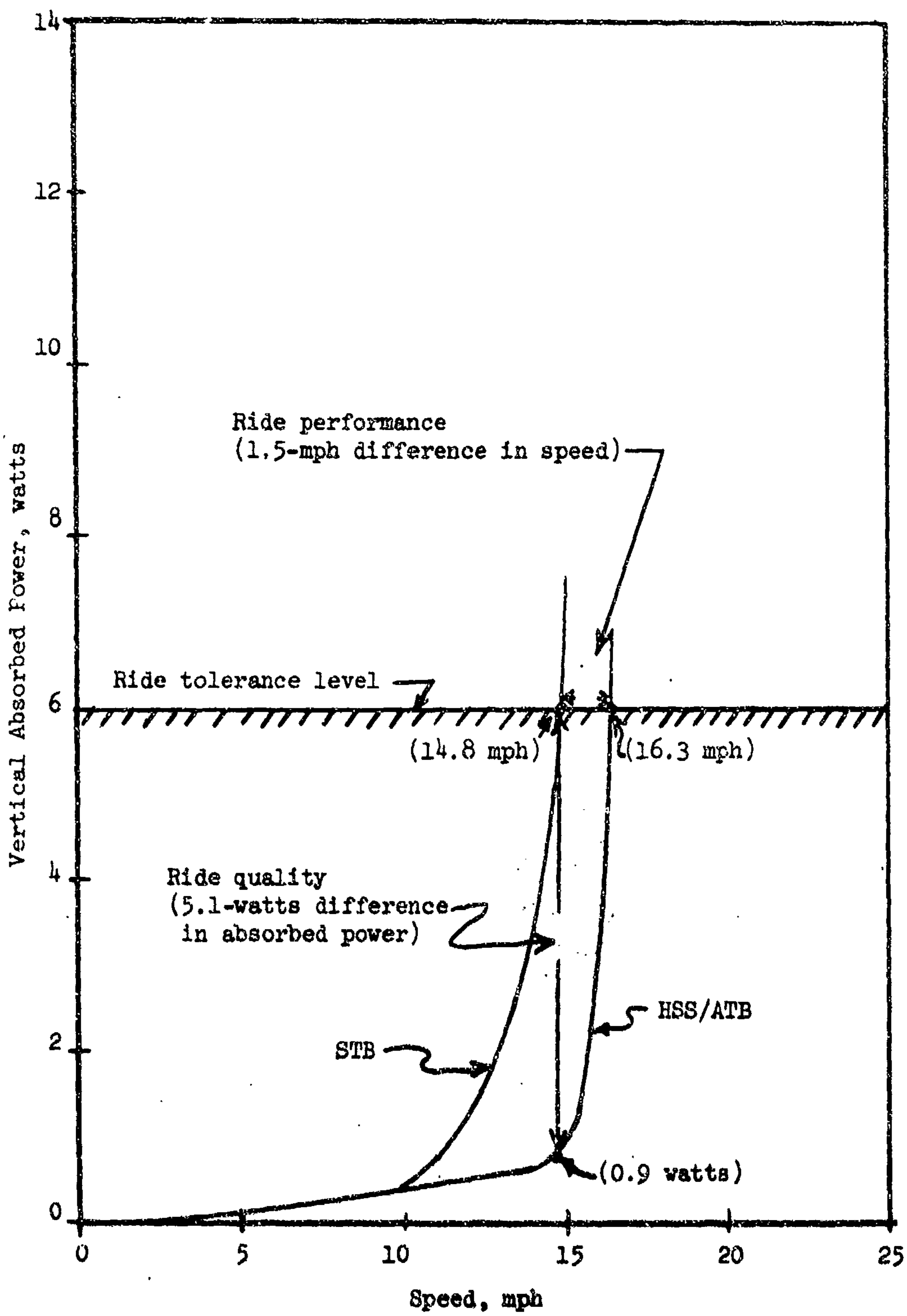
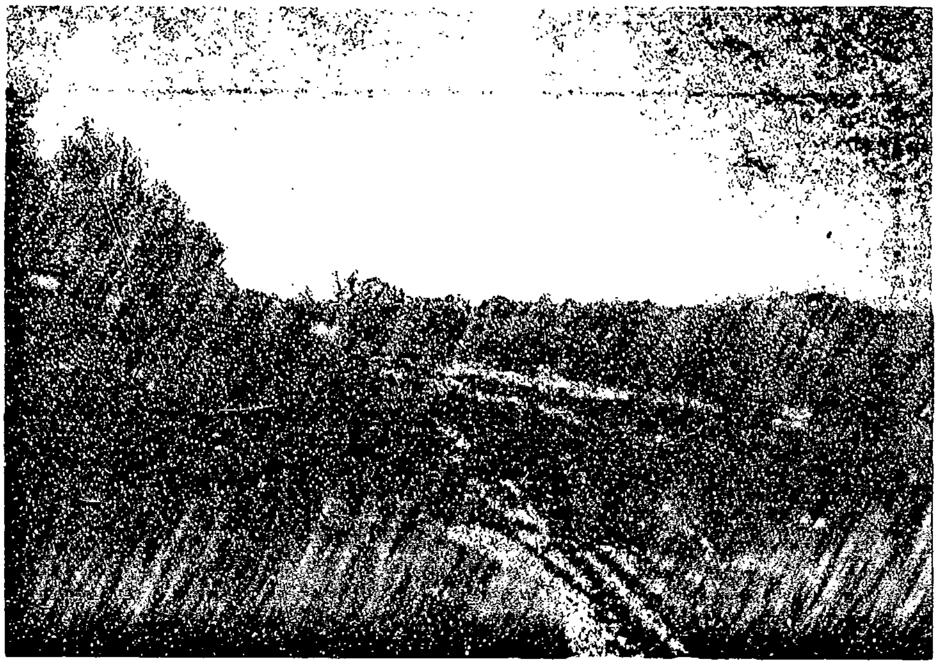
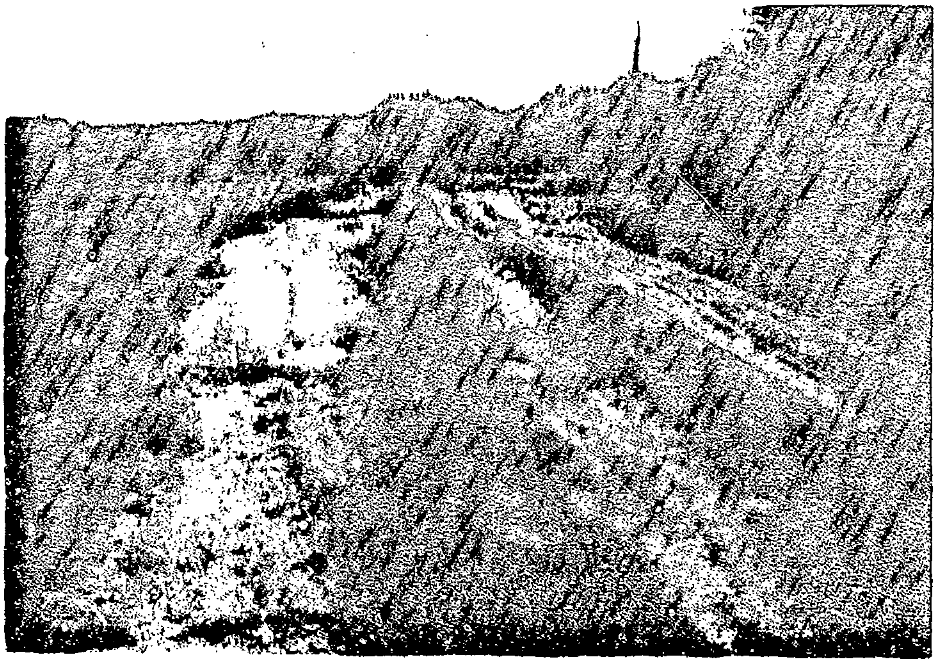


Figure 1. Representative absorbed-power versus speed graph illustrating the distinction between ride performance and ride quality

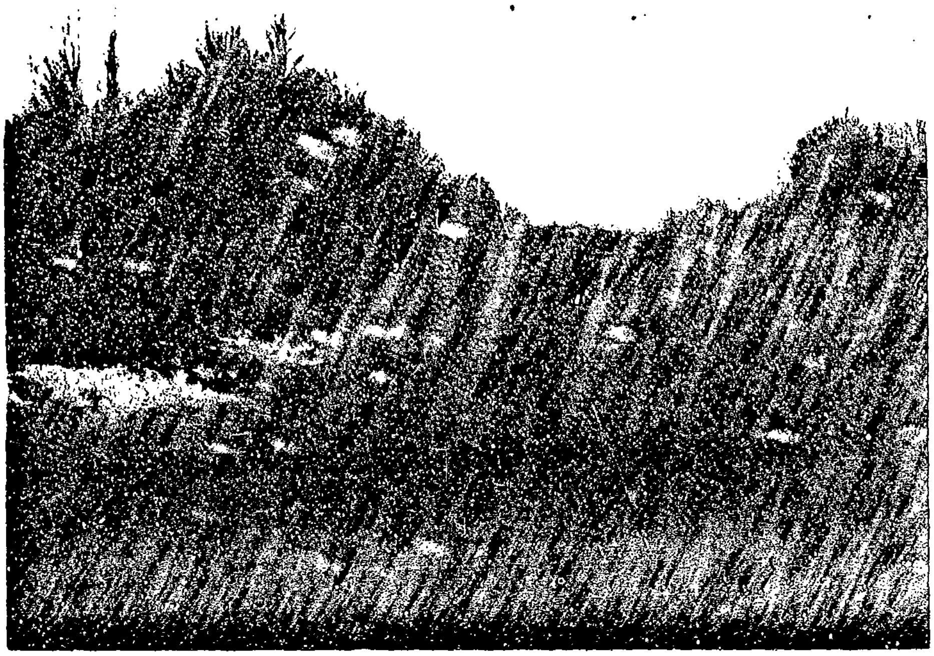


a. Ride course 1, surface roughness = 1.1 rms, in.



b. Ride course 2, surface roughness = 2.8 rms, in.

Figure 2. Ride courses 1 and 2 used in the M60 STB-M60 HSS/ATB hybrid tank test program (Carpenter Test Area, Fort Knox, Ky.)



a. Ride course 3, surface roughness = 1.9 rms, in.

b. Ride course 4, surface roughness = 5.8 rms, in.

Figure 3. Ride courses 3 and 4 used in the M60 STB-M60 HSS/ATB hybrid tank test program (Carpenter Test Area, Fort Knox, Ky.)

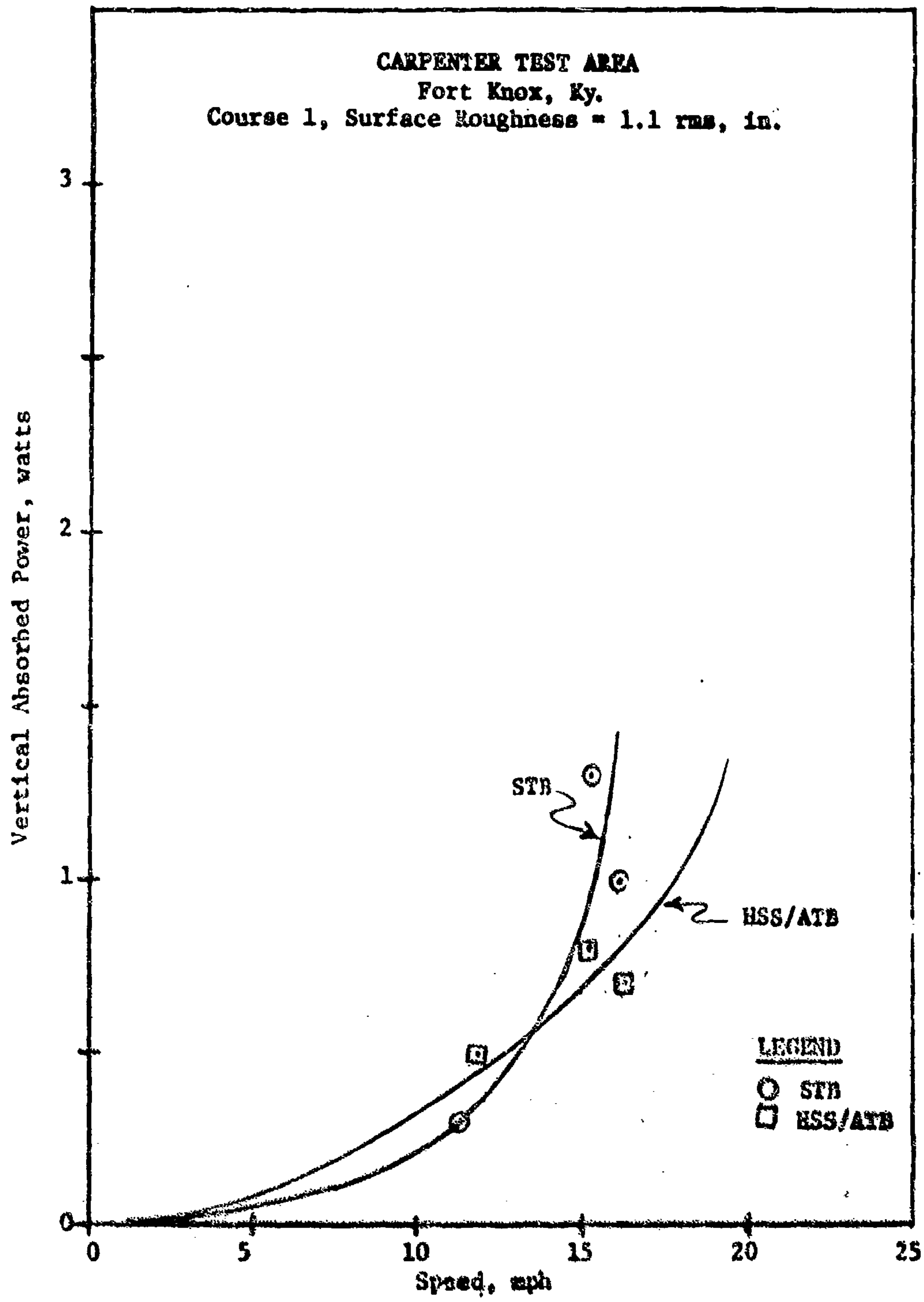


Figure 4. Vertical absorbed power at the driver's seat versus speed on course 1

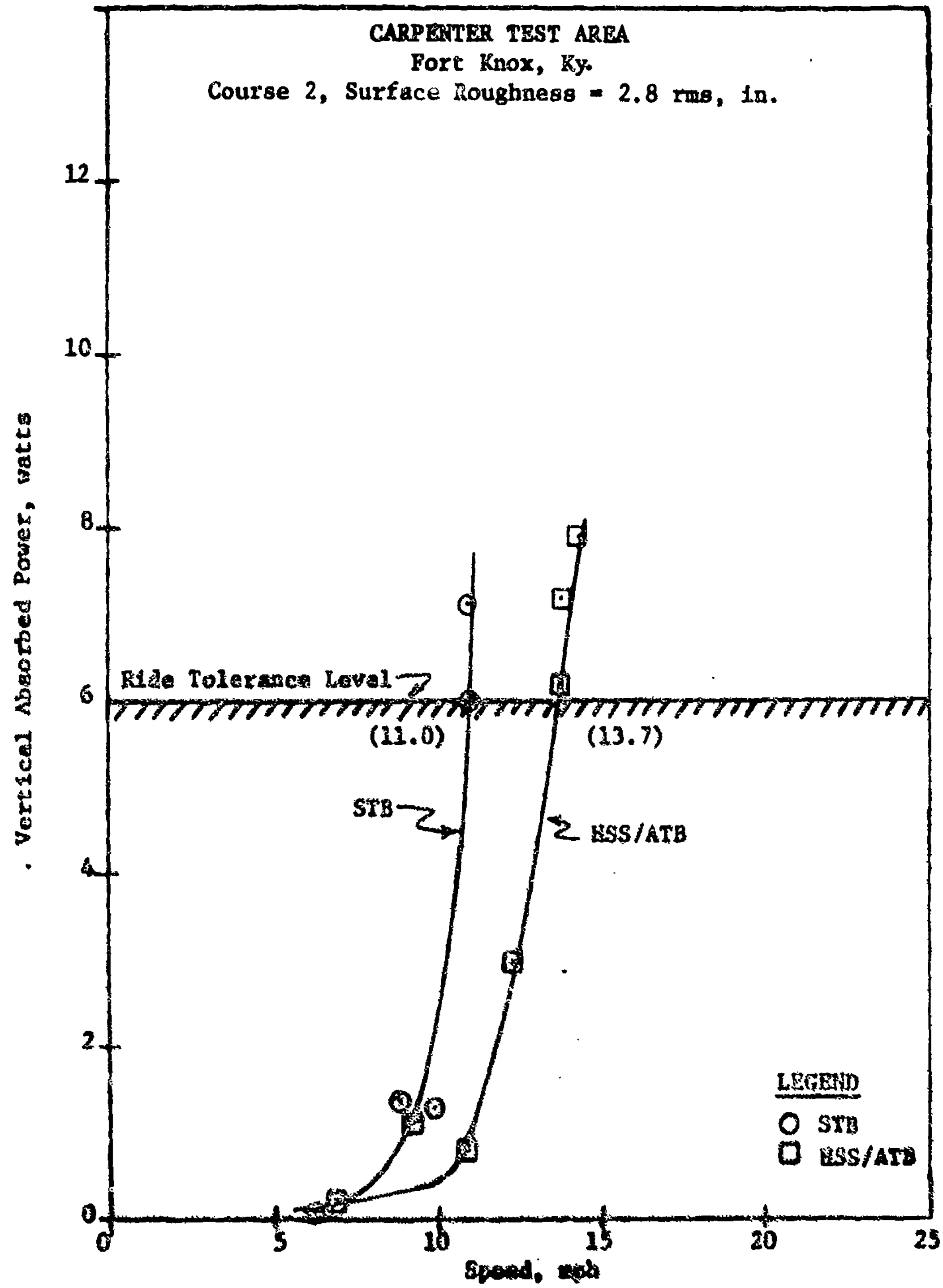


Figure 5. Vertical absorbed power at the driver's seat versus speed on course 2

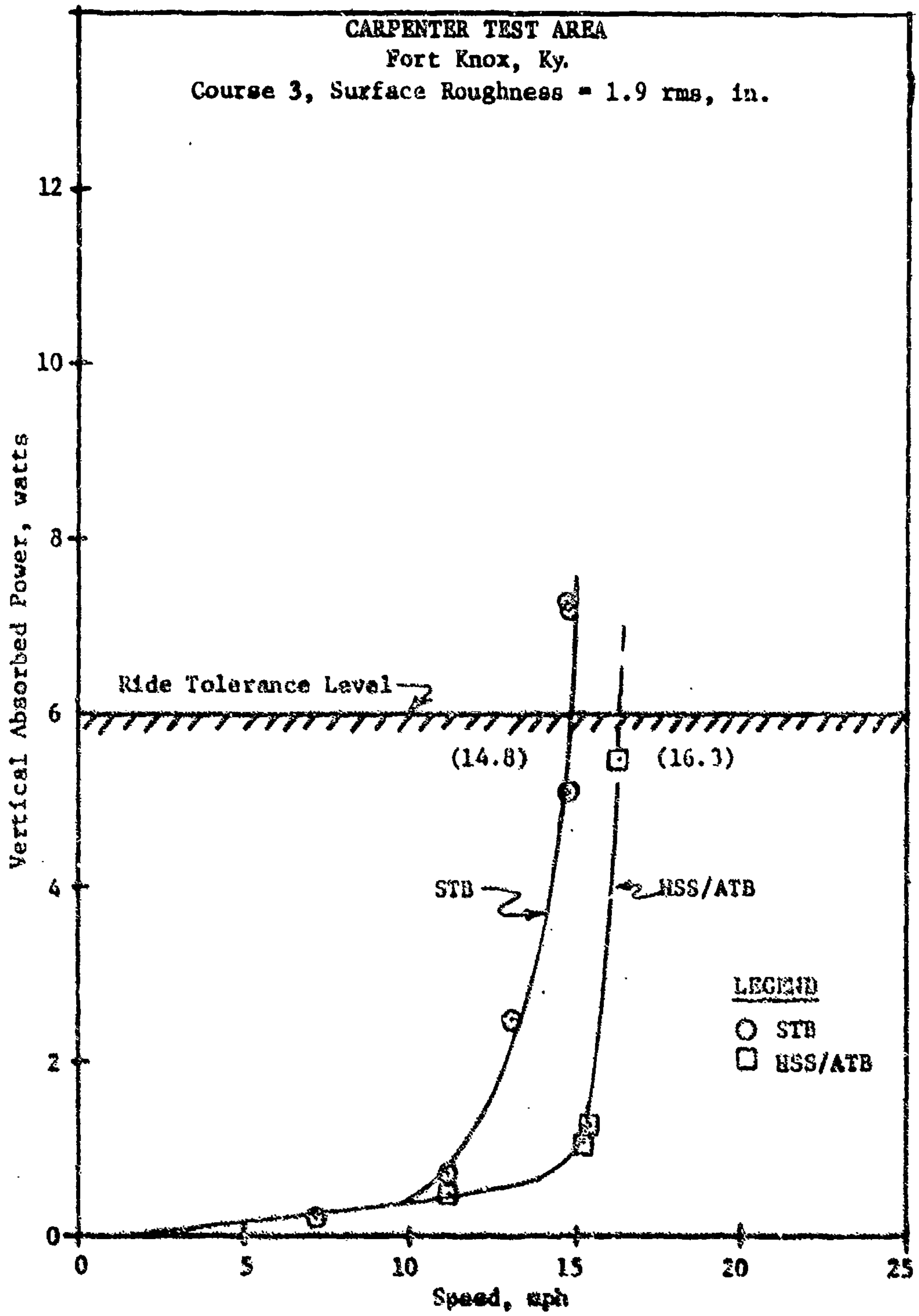


Figure 6. Vertical absorbed power at the driver's seat versus speed on course 3

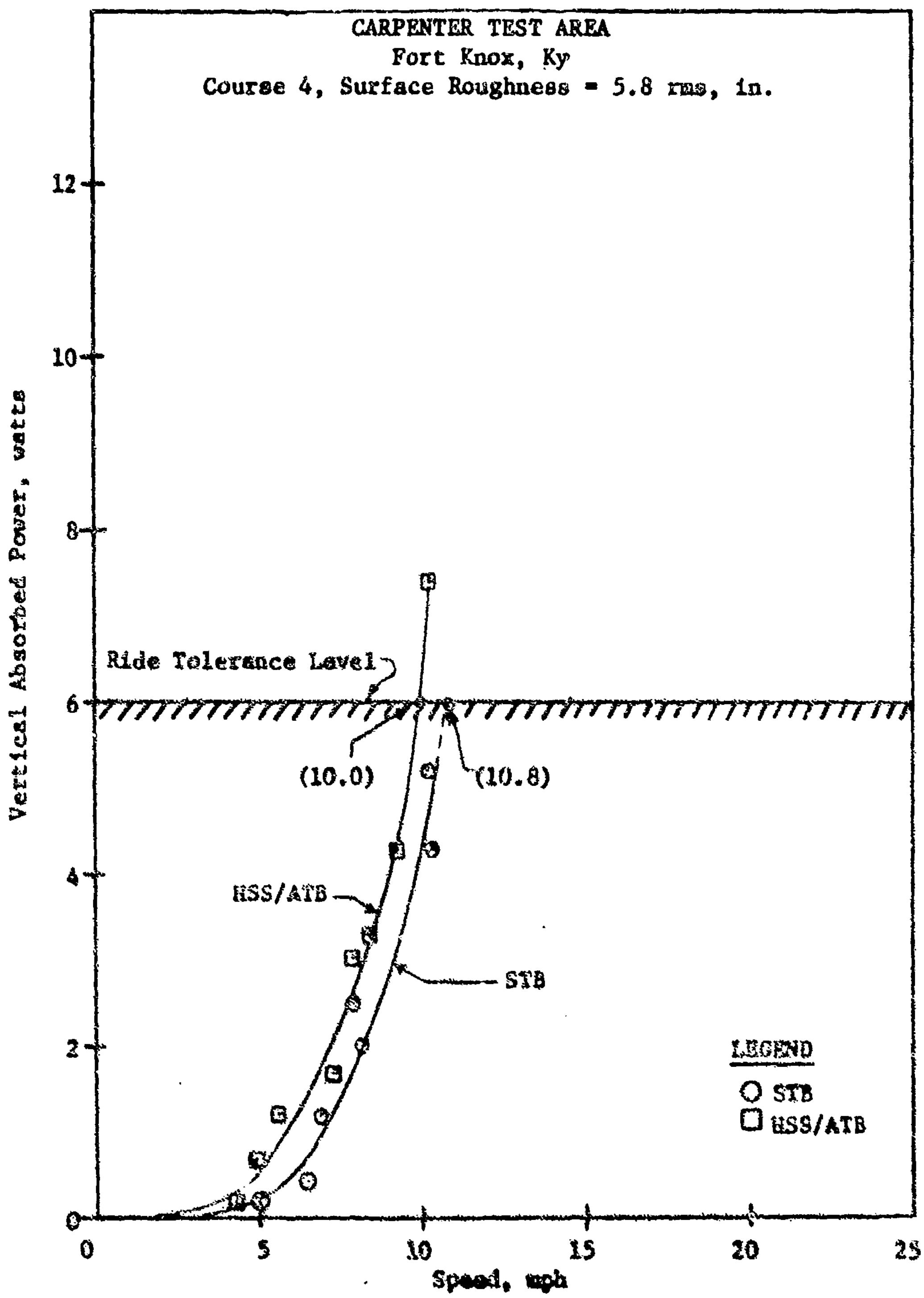


Figure 7. Vertical absorbed power at the driver seat versus speed on course 4

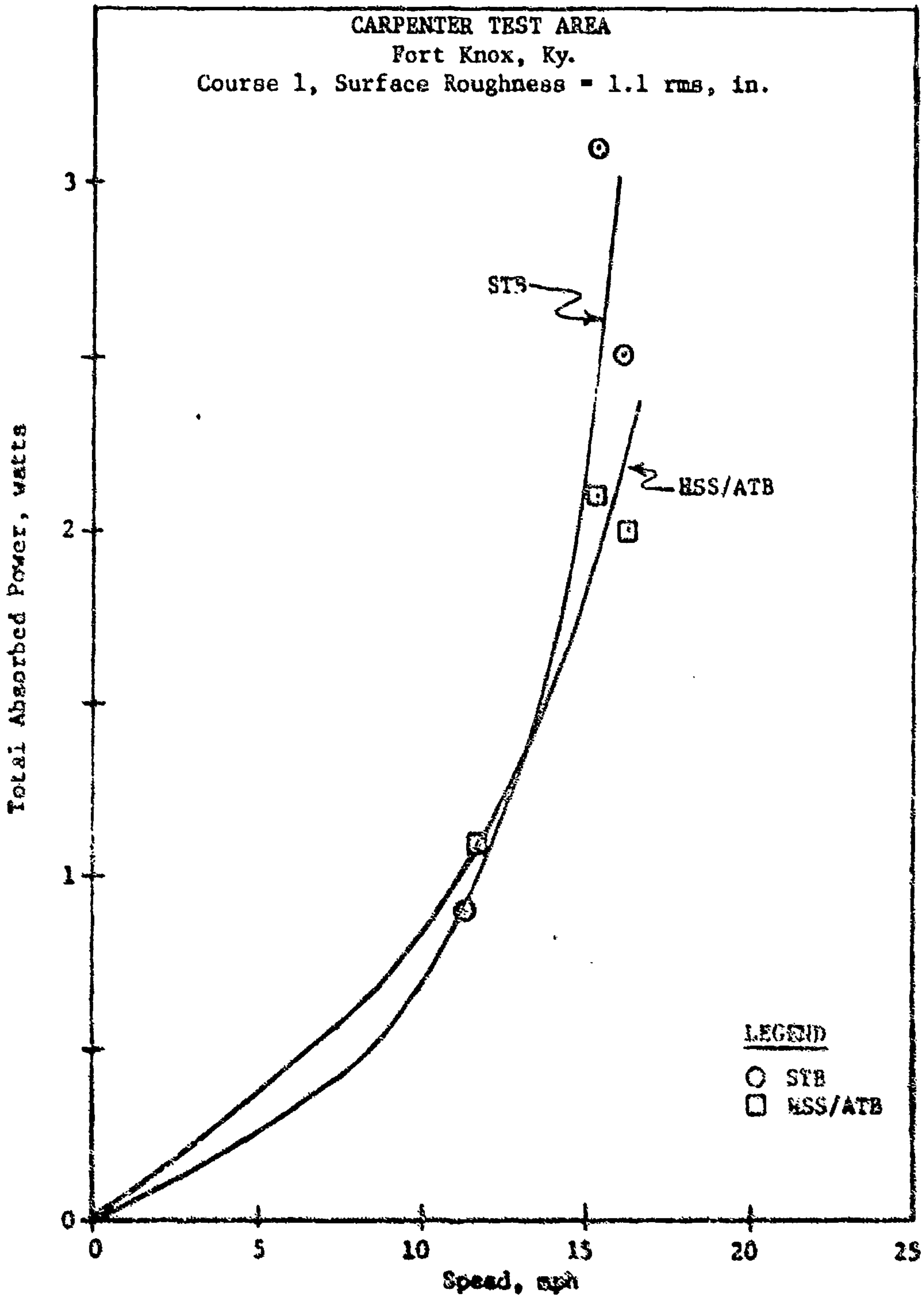


Figure 8. Total absorbed power at the driver's seat versus speed on course 1

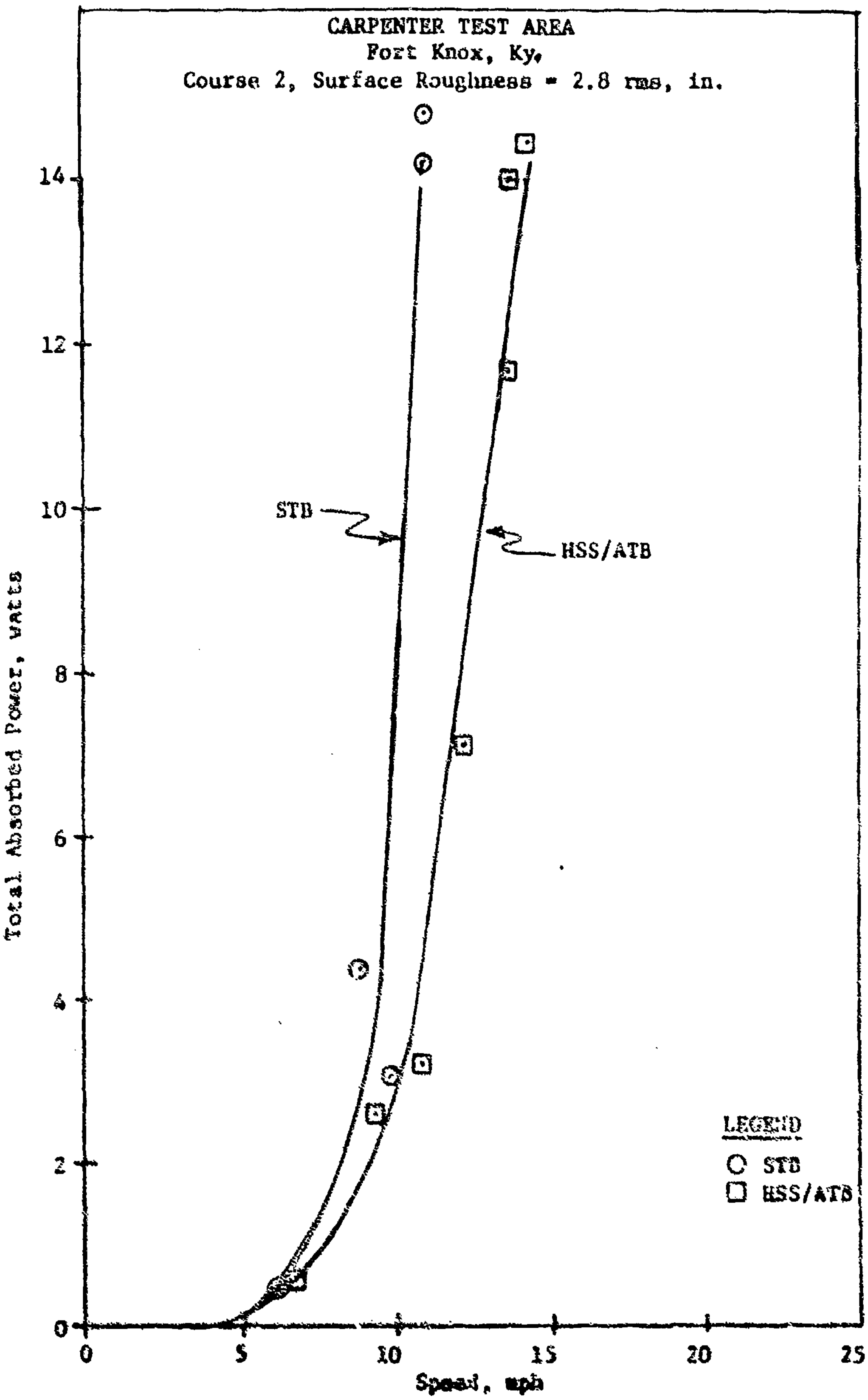


Figure 9. Total absorbed power at the driver's seat versus speed on course 2

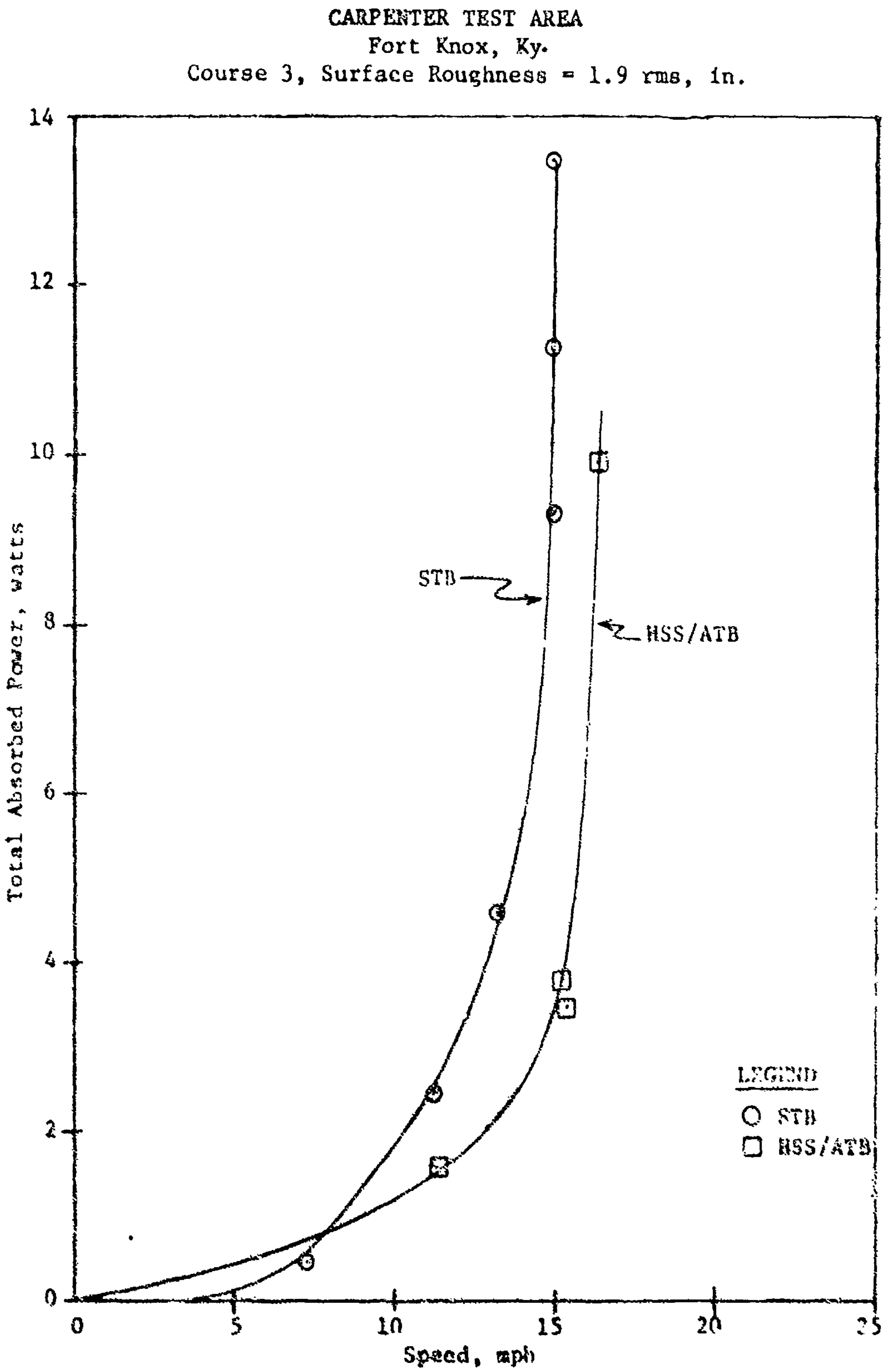


Figure 10. Total absorbed power at the driver's seat versus speed on course 3

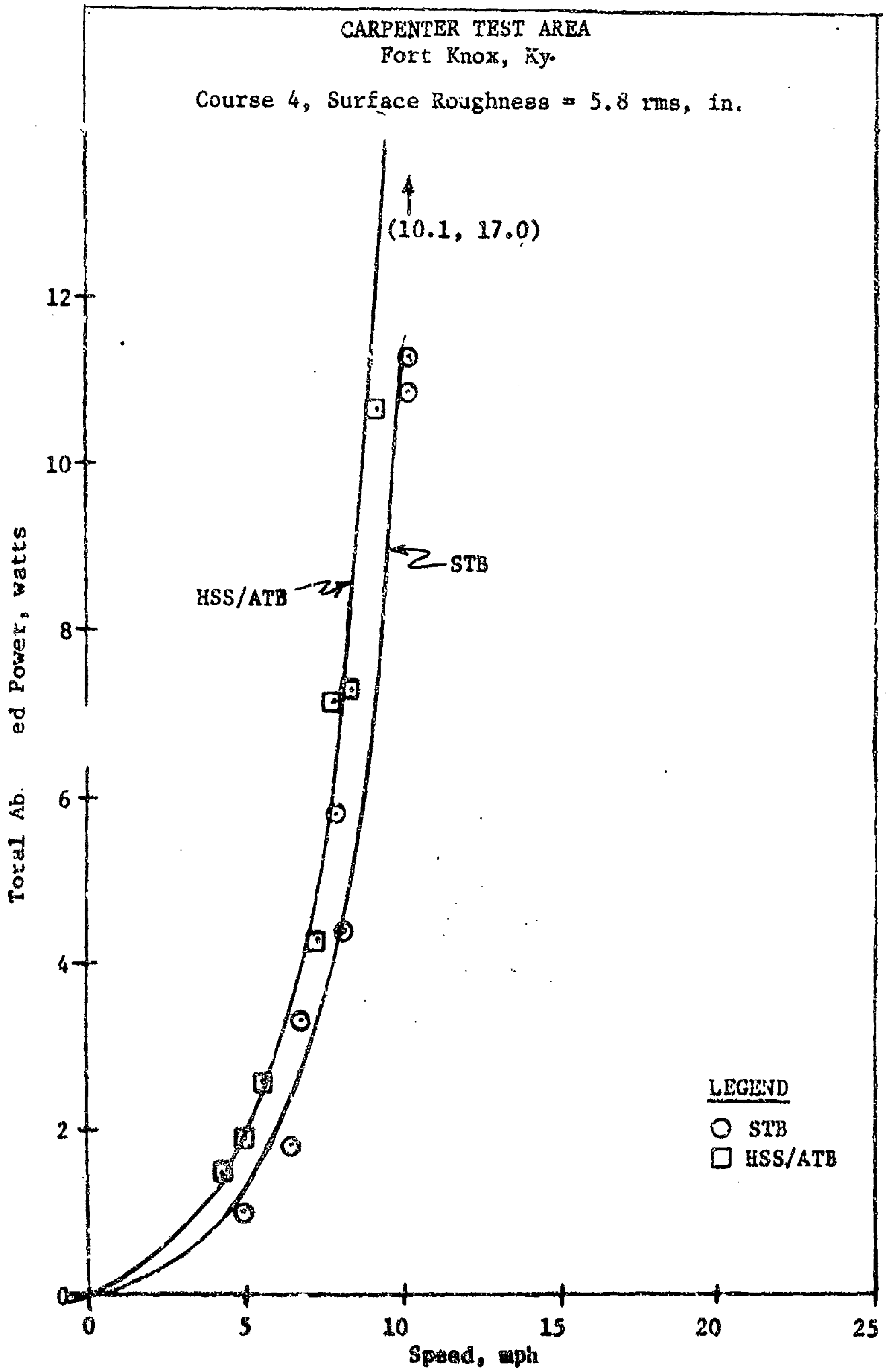


Figure 11. Total absorbed power at the driver's seat versus speed on course 4

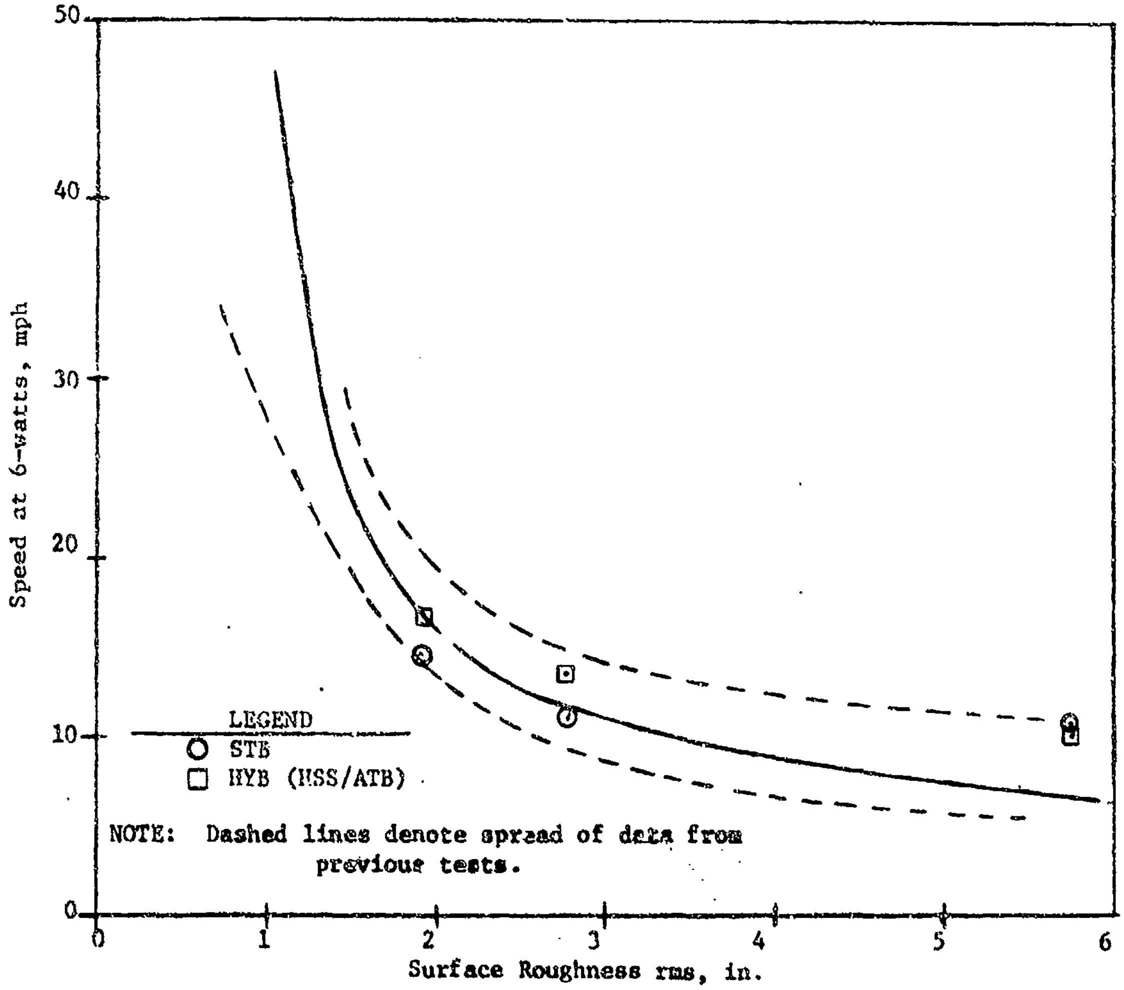


Figure 12. Ride-speed-surface roughness relation for M60 STB and M60 HYB (HSS/ATB)(data obtained from a supplemental test program at Fort Knox, Ky., in March 1977)

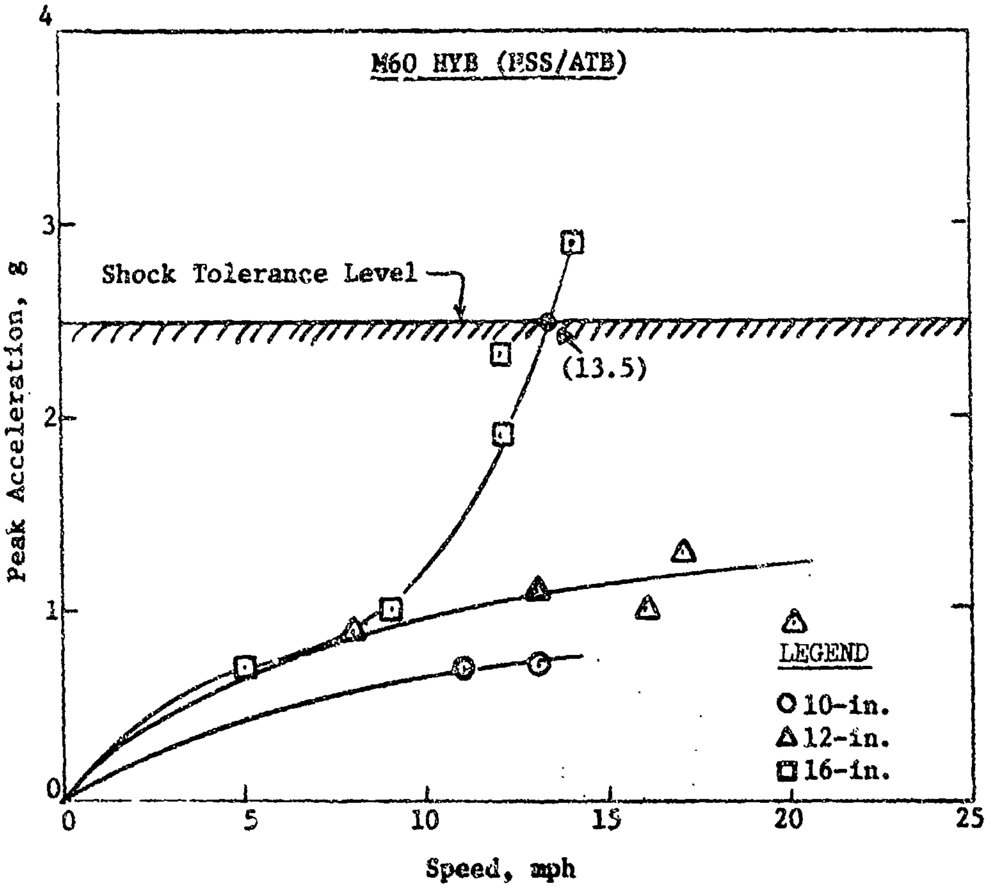


Figure 13. Peak vertical acceleration under driver seat versus speed for M60 HYB (HSS/ATB) tests over discrete obstacles

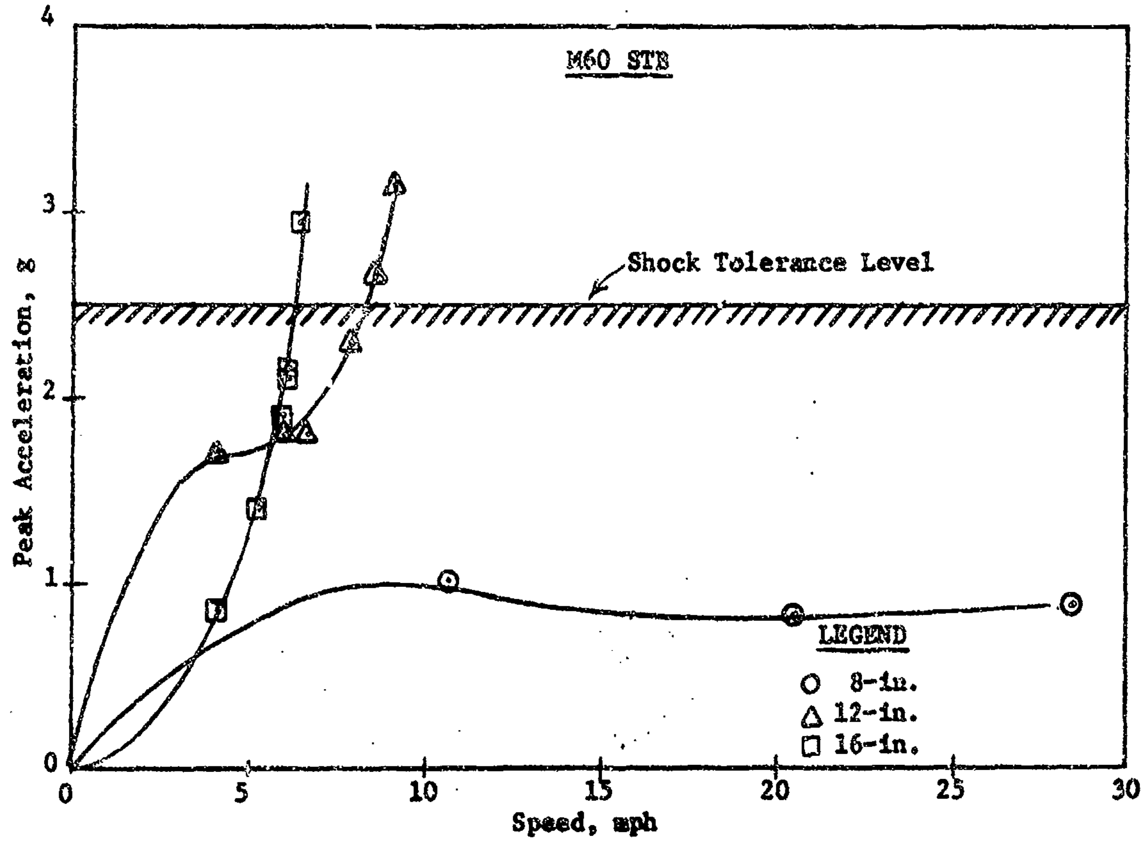


Figure 14. Peak vertical acceleration under driver seat versus speed for M60 STB tests over discrete obstacles (test data from previous test program)

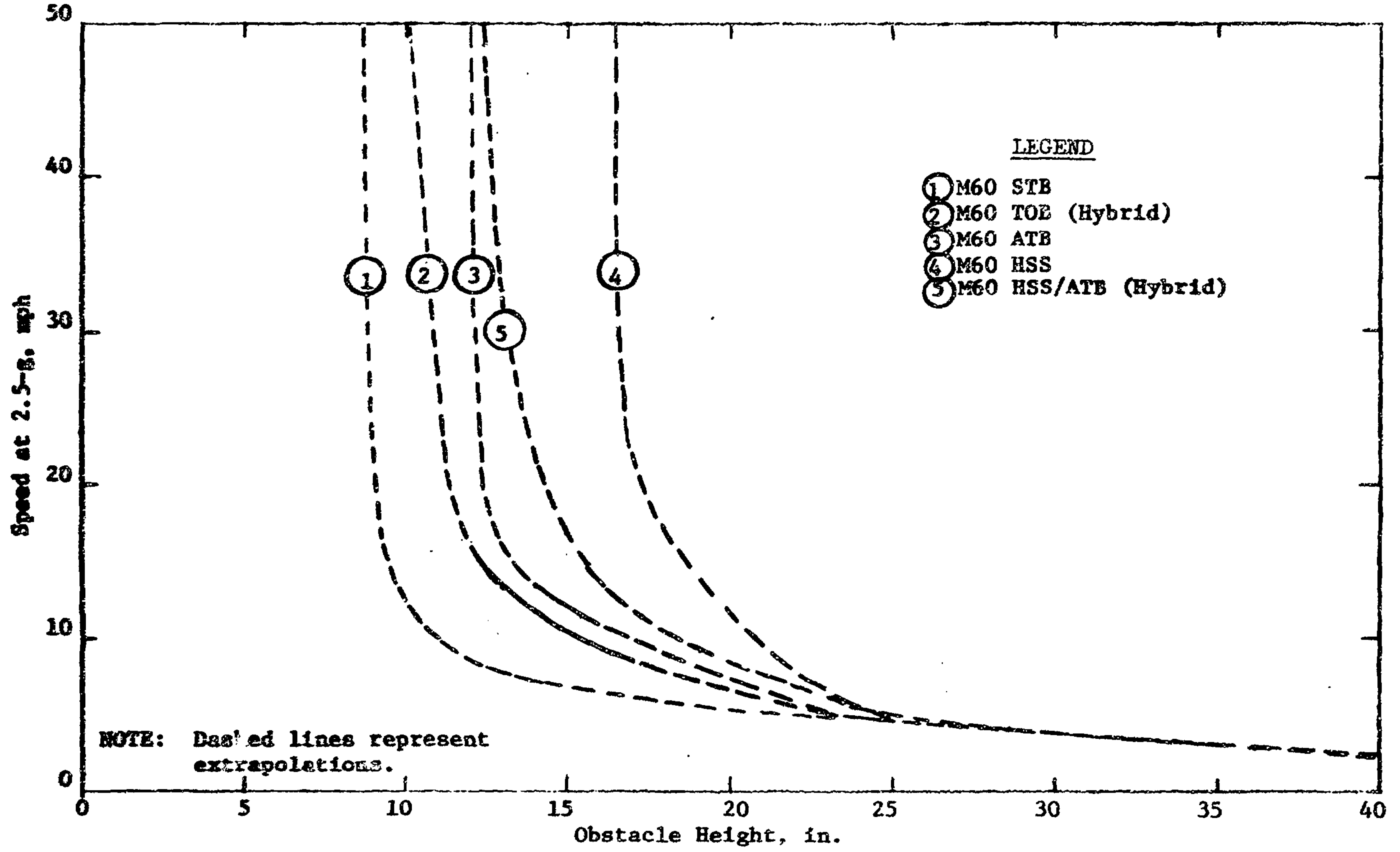


Figure 15. Speed-obstacle height relation for M60 tanks

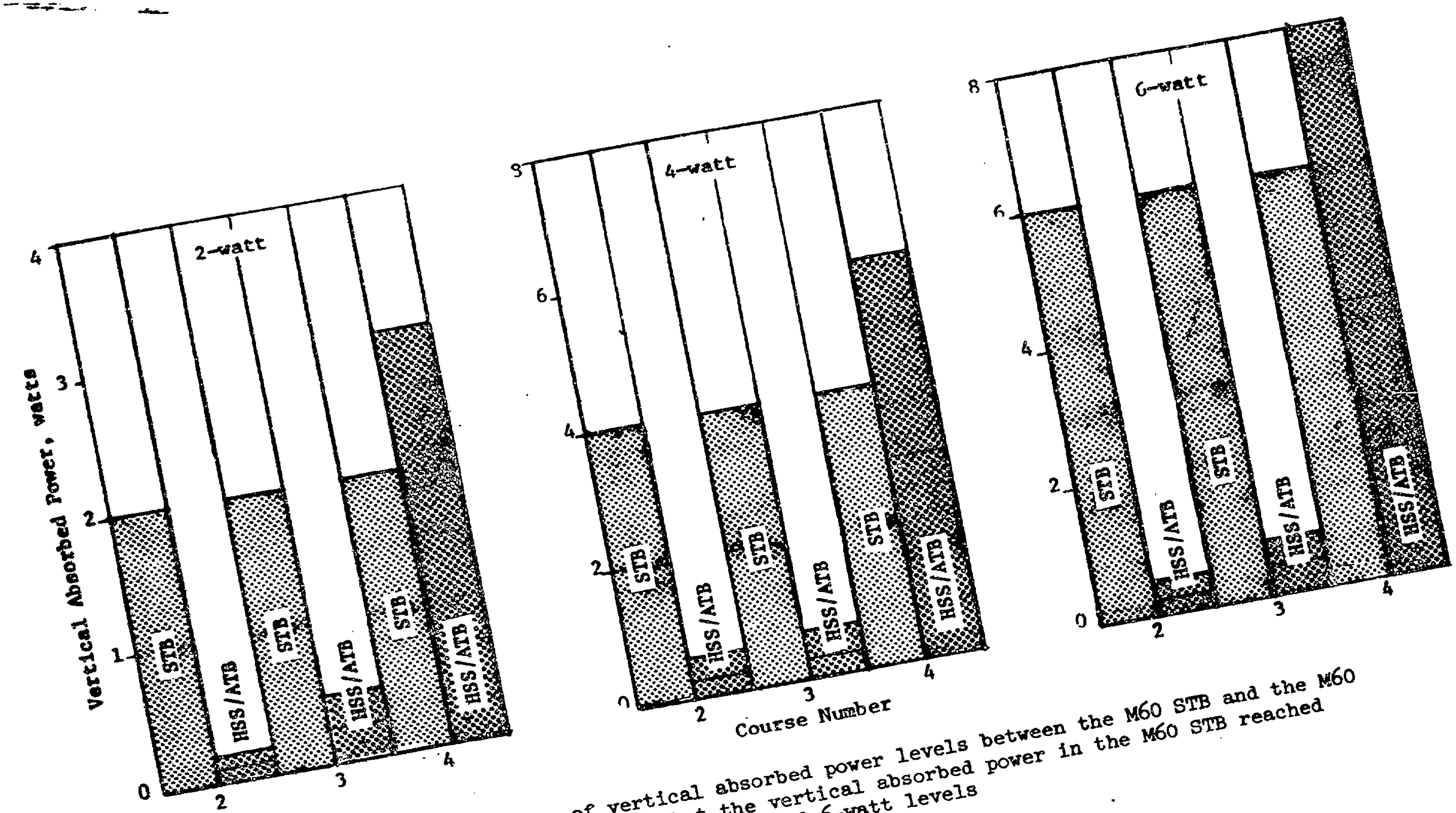


Figure 16. Comparisons of vertical absorbed power levels between the M60 STB and the M60 HSS/ATB hybrid tanks at speeds that the vertical absorbed power in the M60 STB reached 2-, 4-, and 6-watt levels

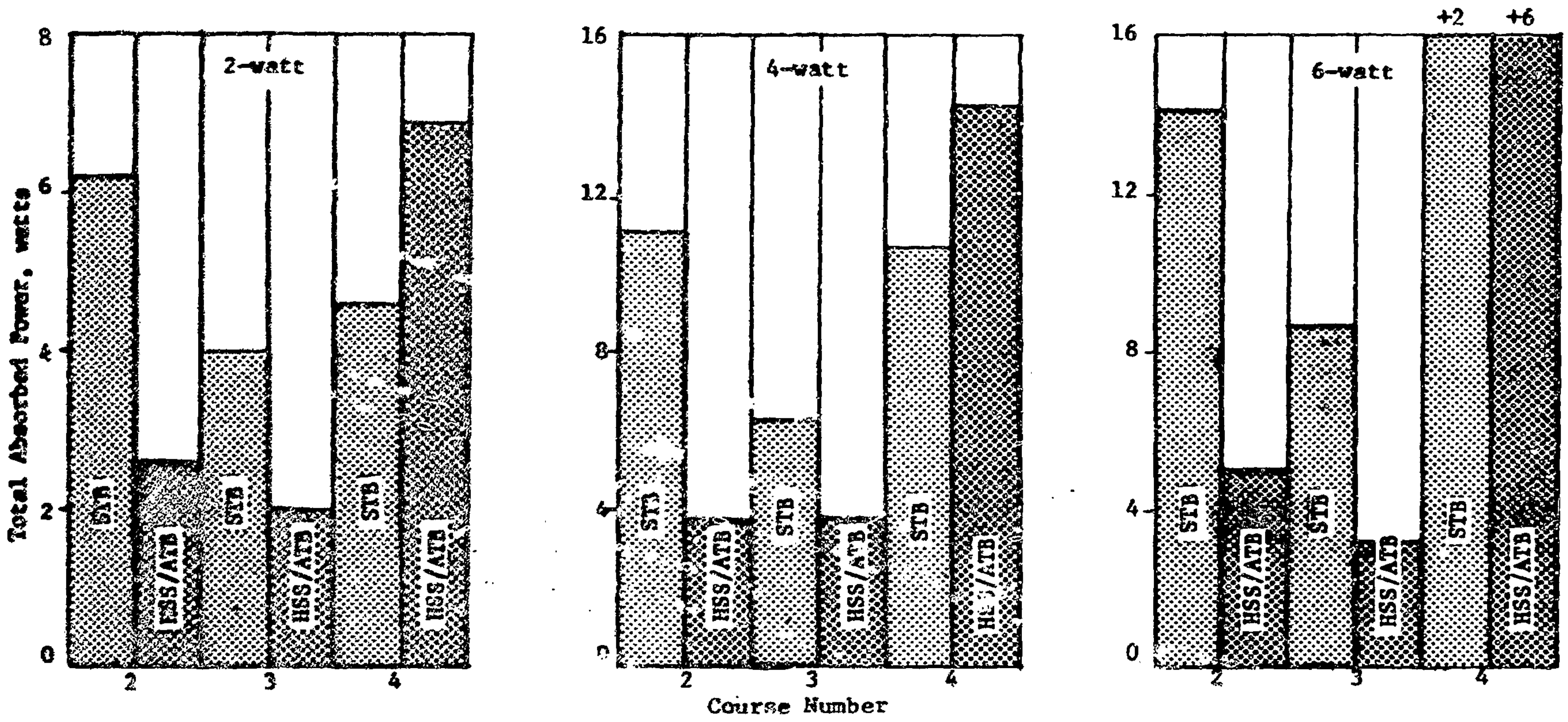


Figure 17. Comparisons of total absorbed power levels between the M60 STB and the M60 HSS/ATB hybrid tanks at speeds that the vertical absorbed power in the M60 STB reached 2-, 4-, and 6-watt levels

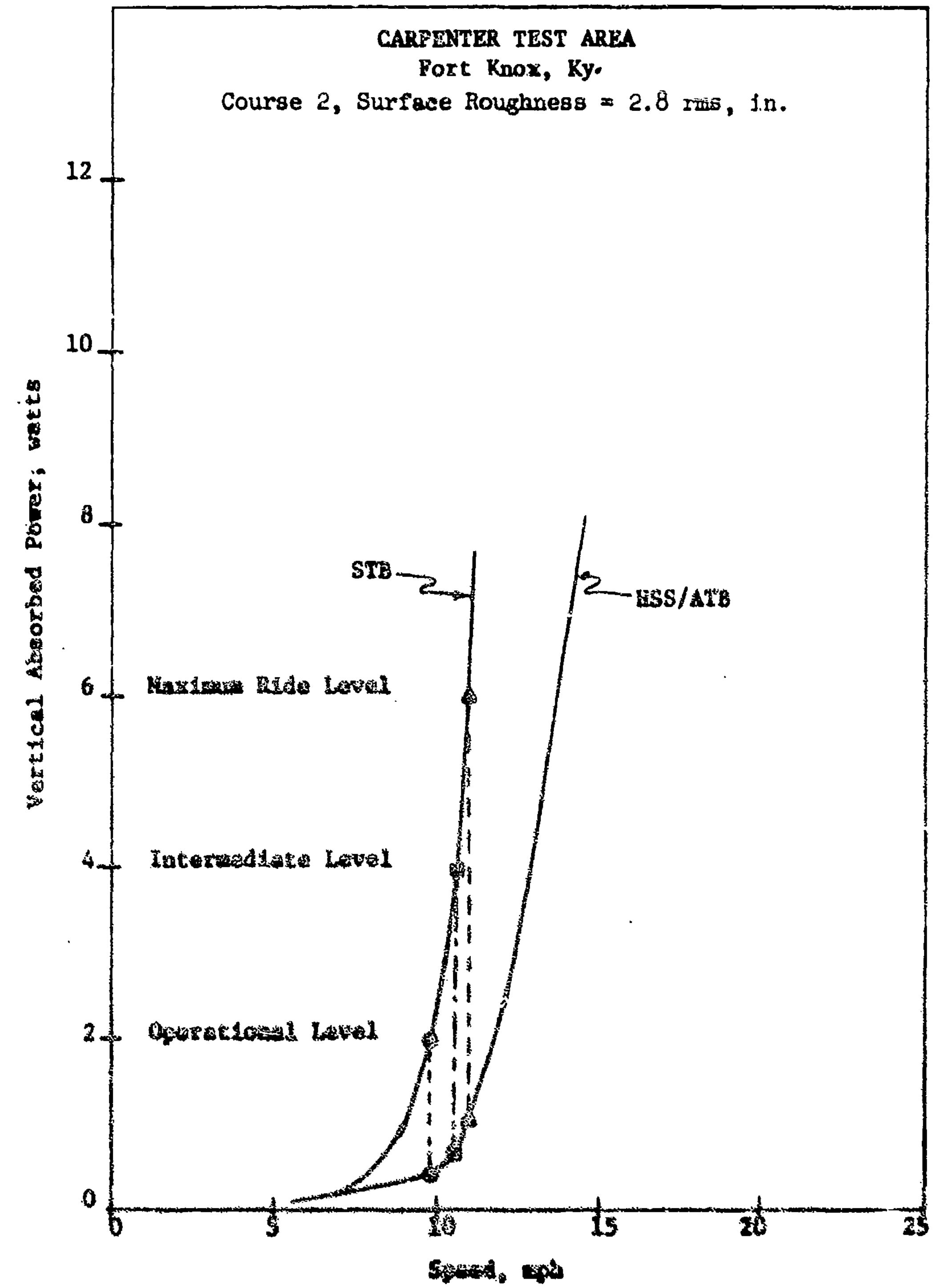


Figure 18. Absorbed power-speed plot highlighting the respective absorbed power levels at the speeds that 2-, 4-, and 6-watt levels occurred in the M60 STB tank

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Murphy, Newell R
Comparison of the ride and shock responses of the M60 STB and the M60 NSS/ATB hybrid tanks / by Newell R. Murphy. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. : available from National Technical Information Service, 1979.
22, [22] p. : ill. ; 27 cm. (Miscellaneous paper - U. S. Army Engineer Waterways Experiment Station ; GL-79-2)
Prepared for M60 Project Manager's Office, Warren, Michigan.

1. Tanks (Combat vehicles). 2. Ride dynamics. 3. Terrain. 4. Off-road vehicles. I. United States. Army Tank-Automotive Research and Development Command. II. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Technical report ; GL-79-2.
TA7.W34m no.GL-79-2